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Feasibility Study of Using Recycled Waste Plastic in Bituminous Concrete

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Abstract

The road has been used in many different loading types, affecting their performance. The increase in traffic of the vehicles is the main factor causing road damage, and including the problems of increasing environmental pollution causing to involves us thinking about improving the pavement characteristic and quality of the road pavement by using polymer modification materials that satisfy both the strength and economic aspects. Thus, this study aims to find the best combination of bitumen and plastic for long-term performance by comparing the stability of conventional and modified bituminous concrete. This study investigates the behavior of bituminous concrete mixed with bottle caps as recycled plastic waste in two processes the wet and dry processes. The various percentage of recycle plastic waste of 2%,4%,6%,8%,10% and 3%,4%,5%,6%,7%,8% were used in dry process and wet process, respectively. Marshall test properties such as stability, flow value, air void, etc., are used to determine the optimum recycling of plastic waste content. The result indicated improvement of the modified binder of the wet process's engineering properties and increases the mechanical properties of the bituminous concrete. The 8% of the recycled plastic content showed the maximum marshall stability of the wet process and optimum value for the dry process. The recommended method for use in toad construction is the dry process. It improves the base bitumen and stability, which resistance to deformation, rutting, and shear stress.

Keywords

Bituminous Concrete, Modified Bitumen, Plastic Bottle Cap, Wet Process, Dry Process

Introduction

The road is one of the most fundamental forms of social infrastructure, and it plays a critical role in boosting the local economy. Routes can also make it easier to provide education, health care, and social service to humankind. The continuous growth in commercial vehicle traffic, including the considerable change in daily and seasonal temperature, demand enhanced road characteristics. As a result, road pavement enhancement research is required to ensure the upcoming generations' survival (Bhardwaj et al., 2017). The essential binder material for road construction is a bitumen. Bitumen binder and aggregate are commonly utilized to produce bituminous concrete for road construction. The material used in the production of bitumen pavement is chosen to provide the most cost-effective solution to meet traffic and environmental demands. The materials—aggregates, bitumen, and additives—must be carefully selected. It is necessary to consider availability, costs, and the impact on performance (Hansen et al., 2000).Phnom Penh, Cambodia, faces a considerable waste management challenge due to the rapid economic andindustrial growth. It has increased the impact on the environment by more than 3,000 tons everyday (Keo Rathana, 2009). Landfilling, incineration, and random littering are currently the most popular waste disposal options in cities, municipalities, and the countryside. Unfortunately, these disposal methods are harmful to human health

and the environment, and as a result, rivers, gutters, and roadsides are clogged with waste plastics. In a developing country, Plastic waste is known as a serious problem that can impact both economic and environmental (Beresford, 2020). Therefore, research on using waste materials is necessary for bitumen road construction. Waste plastic polymers could be utilized as a long-term and cost-effective component for improving bitumen qualities, resulting in a challenging situation for the environment and the economy. Adding the recycled plastic waste into the bitumen is known as modified bitumen, which improves the properties of bitumen. It enhances various properties (rutting resistance, wearing resistance, stripping resistance, oil resistance and durability, etc., Long-life pavement) of bitumen mixtures. Therefore, a massive increase in environmentally responsible plastic waste recycling. Using waste materials instead of new resources has two significant advantages in the road construction industry: reducing costs and waste in landfills (Mashaan et al., 2021).

Research Materials and Methods

1. Materials

a) Bitumen 60/70

Bitumen 60/70 was selected as the bituminous material in this research. The test performance of the laboratory to evaluate the properties were ductility, softening and penetration, and density. **Table 1**, indicated the properties of the bitumen

Table 1. The Physical Properties of Bitumen 60/70

Property	Test Method	Spec	Result	Unit
Ductility Test	ASTM_D113	>=100	150	cm
Softening Point	ASTM_ D36	45-55	50.2	°C
Penetration Test @ 25°C	ASTM_D5	60-70	66.72	0.1 mm
Density	ASTM_D70	-	1.032	g/cm3

b) Aggregate

The mineral aggregate material was obtained from Takream Mountain, located North-West of Cambodia. The laboratory test performance of the coarse aggregate and fine aggregate were specific gravity, water absorption (AASHTO T 85), abrasion loss (ASTM C 131), and flat and elongated particle (ASTM D 4791), as shown in **Table 2**. The Ministry of Public Works and Transports specification was used to define the gradation of the wearing coarse, as shown in **Table 3**.

Table 2. The Physical Properties of Aggregate

Property		Test Method	Unit	19-12.5	12.5-5	0-5	Sand	Specification
Specific Gravity	Bulk (Dry Basis)	AASHTO T85	(g/cm^3)	---	---	2.566	2.581	---
	Bulk (SSD)		(g/cm^3)	---	---	2.603	2.617	---
	Apparent		(g/cm^3)	---	---	2.663	2.677	---
Water Absorption			(%)	---	---	1.41	1.39	---
Abrasion Loss		ASTM C 131	(%)	18.96	18.96	---	---	<40
Flat Particle		ASTM D 4791	(%)	12.00	21.19	---	---	<35
Elongated Particle			(%)	14.24	13.94	---	---	<35

Table 3. Blending proportion of Aggregate

Aggregate Size(mm)		Min. Spec	Max. Spec	Result
Percentage Passing by Mass	19	100	100	100
	12.5	---	---	---
	9.5	60	83	75.6
	4.75	40	65	57.5
	2.36	30	50	41.5
	1.18	20	40	29.6
	0.6	15	35	21.2
	0.3	10	25	13.9
	0.15	7	17	9
	0.075	4	9	6.7

3. Recycled Waste Plastic of Bottlecap

The plastic polyethylene terephthalate(PET) bottle cap is an assembly of commingled plastic from post-consumer recycling operation, which includes various types of plastic, including polypropylene (PP), low-density polyethylene (LDPE), and linear low-density polyethylene (LLDPE). For the plastic bottle cap, the heating testing at 180°C for 90min showed the exciting result of the melting plastic that contains is suitable as the period for mixing the Modified Bitumen. Noticeably, the RPW consisting of the melting point below 200°C was considered a suitable material for bitumen modification (Dalhat & Al-Abdul Wahhab, 2017). **Table 4.** indicates the properties of plastic bottle caps used in this experiment (Papacostas, n.d.).

Table 4. The Properties of Plastic Bottle Cap (Papacostas, n.d.)

Physical Attributes	Plastic Bottle Cap (CPE/PP)
Melting Polymer of LDPE (°C)	112
Melting Polymer of LLDPE (°C)	122
Melting Polymer of PP (°C)	163
Density (g/cm3)	0.93
Water Contact Angle (° Degree)	109.3
MFI (g/10min)	3.61

2. Methods

This study selected two effective mixing methods for mixing recycled plastic waste with bituminous concrete. The two processes included the Dry Process and the Wet Process. The binder content of 4.7% was used as the optimum bitumen content for both methods as it is the most effective proportion of binder content.

a) Sample Preparation

The proper design of aggregate blend proportion and the optimum binder content were determined to ensure the excellent performance of the bitumen mixture. Twenty-one samples each of 1200g in weight were prepared according to the mix design to determine the optimum binder content. The various percentage of the bitumen binder (3%, 3.5%, 4%, 4.5%, 5%, 5.5%, 6%) was examined with the standard 75-blow Marshall design method using the automatic compaction machine. As a result, the selected optimum binder content was 4.7%. Thirty-six samples of bituminous concrete were prepared at the optimum binder content of 4.7% including the recycled waste plastic to test the effectiveness with the Dry processes and the Wet processes with the various percentages.

b) Dry Process

The recycled waste plastic (RWP) of the PET bottle cap as dry solids in small particles, which has a maximum flake size of 5mm to 8mm to help produce a uniform dispersion, was added into the hot aggregate by blending before adding the bitumen in the dry process. For this experiment, the selection of recycled plastic waste was 2%, 4%, 6%, 8%, and 10% of the binder. The aggregate was heated at 170°C and mixed with recycled waste plastic as the plastic changed its state to the intermediate molten state and added with the pre-heated bitumen 60/70 of 150°C. The mixing of the bitumen with the recycled plastic waste was to coat the surface of the aggregate. The mixing temperature was around 158°C to 164°C, in which both materials of plastic and bitumen were in the liquid state based on the kinematic viscosity testing and the maximum melting point of the plastic.

c) Wet Process

The wet process is the method of adding recycled plastic waste of PET bottle cap into the bitumen equivalent with a specific time and temperature known as Modified Bitumen. The selection of plastic by weight of bitumen was 3%, 4%, 5%, 6%, 7%, and 8% used to investigate the change of the bituminous concrete. First, the bitumen 60/70 was heated to 150°C to ensure that the bitumen was liquid, allowing the plastic to melt equally. Added the recycled waste plastic, increased the temperature between 180°C to 185°C for 90minute, and remained stirred the whole time.After mixing, pre-heat the modified bitumen and aggregate to 160°C was selected to be combined with the modified bitumen due to changes in bitumen properties. The mixing temperature was around 158°C to 164°C, in which both materials of plastic and bitumen were in the liquid state based on the kinematic viscosity testing of base bitumen and the maximum melting point of the plastic.

Result and Discussion

1. Result

The properties of the bitumen mixing with the recycled waste plastic have been shown in **Table 5**. As the result shown, the more content of plastic, the ductility value and penetration value of bitumen had been decreased which shown the loss of cohesion ability of the bitumen and change the grade of the bitumen causing the bitumen harder than the conventional bitumen. In the other hand, the softening point increase showed it more resistance to the higher temperature in the working periods.

Table 5 The Properties of bitumen content different from Recycle Waste plastic

Sample No.	Plastic Content (%)	Penetration Value (mm)	Ductility Value (cm)	Softening Value (°C)
1	0	66.72	150	50.2
2	3	45.5	68.62	56.9
3	4	36.1	33.38	58.9
4	5	37	27.31	62.3
5	6	27.31	15.17	65.8
6	7	17.67	11.18	76
7	8	26.06	10.97	85.45

a) Air Void

Air voids are the airspace between the aggregate particle in the final compacted mix. The advantage of the air voids is to allow additional compaction under traffic. Usually, the allowable percentage of the air voids is between 2% to 4%. The dry process results indicate that using recycled waste plastic as a modified asphalt affects the air void of the B.C. mixture, which increases the air void of the mix. In contrast, for the wet process, air voids were decreased at the first 6% and recovered little by little along with the increase of the plastic content. This result may show the maximum plastic Content in the bitumen that can be mixed. However, more tests should be conducted to verify the maximum plastic combined with the bitumen. **Figure 1** illustrates the result of air void in both dry and wet processes.

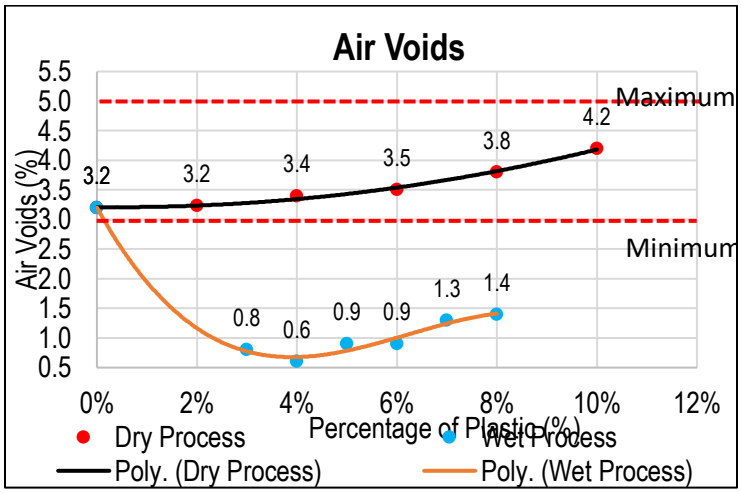

Figure 1 Air Voids

b) Marshall Stability and Flow Value

The Marshall stability at 60°C is the value resistance of the bituminous concrete to deformation, rutting, and shearing stress.**Figure 2** illustrates that the Marshall stability of using direct recycling waste plastic (wet process) into bitumen mixture shows their effective result of increasing the Marshall stability compared to the dry process. As a result, the dry process's marshall stability is nearly 17kN as the optimum strength, while the optimum power of the wet process is above 20kN and still shows the trend of remaining increases. So, the stability value of both methods of the mixtures met the government specification of Cambodia of not less than 7kN. The result indicated that the wet mixing process provides a more significant influence than the dry process. However, the increase in stability can improve adhesion between the binder and the aggregate. However, more tests like the indirect tensile fatigue test, etc., would be conducted in future studies to be confirmed.

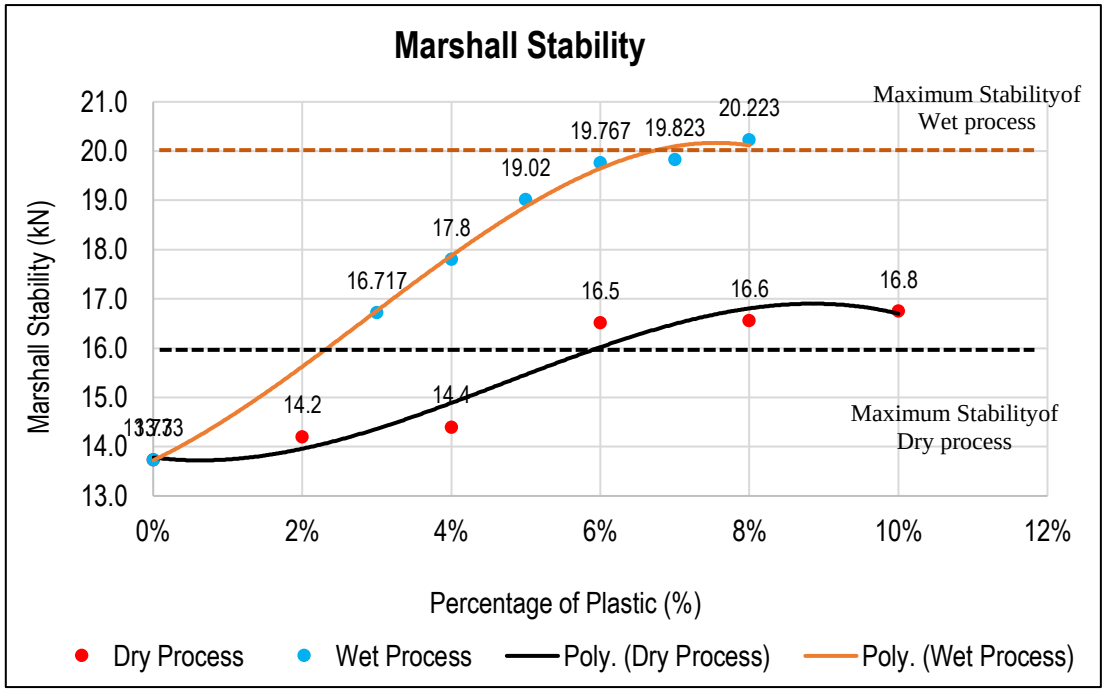

Figure 2 Marshall Stability

The Marshall Flow value is referred to the maximum deformation of the bituminous concrete mixture to the maximum load. Figure 3 shows the result of the flow value. The result in both processes illustrates; that the flow value is a slight change in the wet process. In contrast, the flow value increased for the dry process, and the recycled plastic waste content increased. It has to be said that the flow value does not explicitly reflect the permanent deformation resistance of the bituminous mixture. Further tests, including wheel tracking, should be carried out to evaluate the permanent deformation resistance. The increase of the flow value in the dry process may cause by the un-melting plastic Content in the bituminous mixtures.

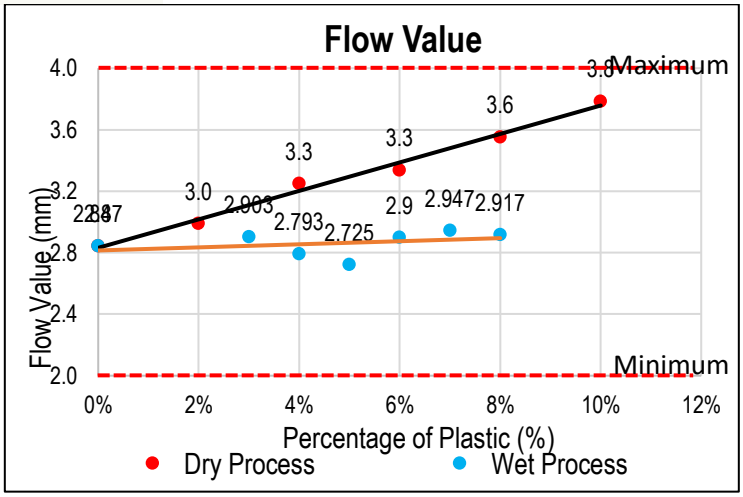

Figure 3 Flow Value

2. Discussion

In the dry process, the result obtained from the experiment demonstrated the acceptable bitumen mixture performance, including the increased of the Marshall stability, flow value, and air void, which also meet the requirement of the Cambodia Ministry of public works and transport (MPWT) specification as the Marshall stability is not less than 7.0 kN, the flow remains between 2mm to 4mm, the air voids in the mix is 3% to 5%. The air voids

had showed the method of the dry process is adequate to provide space for the expansion of bitumen binder to prevent bleeding and reduce skid resistance. Additionally, due to the plastic content shown a significant result of the Marshall stability between 6% and 8% of the recycled waste plastic content and better than the conventional bituminous concrete with the method of directly adding the solid plastic waste to the hot aggregate, it had been considered to be selected as an optimum plastic content, however the flow value also necessary to be considered because it may cause easily cracking or rutting to the road pavement. Ever thought the Marshall stability of 6% and 8% of RWP content is similar, the flow value of the 8% plastic showed a good result. Therefore, the recycled waste plastic content of 8% in the bituminous concrete was selected as the optimum plastic content to enhance the road characteristic and support the environment with the effect method of disposal the waste. However, using this process, the un-melting waste plastic content should be conducted for further investigation to control the road pavement quality. The wet process considers non-linearity due to the change in the characteristic of the binder (Bitumen and Recycled Waste plastic). Additionally, the recycled waste plastic was used as bitumen replacement or bitumen modifiers in the wet process. Due to the modified bitumen being problematic initially requires a high temperature for mixing, which is affecting the bitumen behavior quality. The primary purpose of modified bitumen is to lessen the amount of asphalt binder in the mixture, which has the added benefit of reducing the quantity of the raw materials. Moreover, for the wet process, as (N. S. Mashaan et al., 2021) studies, a waste plastic content of 4% is achieved good properties of strength, stability, stiffness, durability, and rutting resistance and for the 6% of plastic waste is vital to increase the fatigue life and cracking resistance. As the result obtained from the study had shown the strong road enhancement due to the increase of the Marshall stability of the bituminous concrete mixture. In case of the comparison between conventional and modified bituminous concrete in the wet process, it shown that modified bituminous concrete by using the plastic polymer provide incredible result which better than normal bituminous concrete, also partially reduce the waste and support the environments. The flow value in this process had been shown satisfy result with the flow value is not so much effect of the plastic and remained similar to the normal bitumen. Even though the plastic had impact to the characteristic of the bitumen but the value of the flow value is remaining as normal. Thereby, the modified bitumen positively influences the deformation, rutting resistance, and shearing stress of bituminous concrete. Whereases, the result of the air void and the void fill with bitumen which also an importance result to make a conclusion of the quality of the bituminous mixture was shown un-satisfy result base on the MPWT specification which is highly decrease of the air void and hug increase of the void fill with bitumen. In conclude, from the current result obtained, it cannot be making any clear conclusion of the optimum of plastic content for the wet process, yet. Moreover, the graph of the Marshall stability shows it continuously increase which may require to conducted some more samples test of increasing the plastic content to reach the optimum value of the Marshall stability. Additionally, due to the wet process is a method that strongly effect to the physical properties of the bitumen, another specification for the use of the bitumen modification should be selected for this method that require the trial construction at the actual site condition to verify the working ability and the failure effected by the plastic content and other experiments also should be conducted to ensure the quality of the road pavement to avoid cracking the high traffic volume. Also, the trial construction should be conduct more to make a standard specification of using modified bitumen in the road pavement

Conclusions

The addition of recycled waste plastic of PET bottle caps material used in the bituminous concrete is recommended due to the enhance the overall performance of the binder due to the increase of the bituminous mix compared to the conventional bituminous concrete. The recycled plastic of PET bottle caps showed significant improvement in the physical properties of base bitumen. For the modified bitumen of the wet process, the softening point increased while the ductility and penetration decreased. The result has shown that the stability improved after adding the waste plastic for both the dry and wet processes. It also provides increased properties related to stiffness. Bitumen can be reduced for the plastic that melts, which causes a higher solids content at use temperature.

Therefore, using recycled waste plastic in a bitumen mixture reduces the pavement deformation and rutting resistance and influences the adhesion between the bitumen and the aggregate, and support the environment with the method of reused and reduces plastic waste. Thereby, both processing provides different benefits on the road construction sector based on the actual condition requirement. However, the dry process indicated the suitable result of the bituminous mixture for the usage for the Cambodia specifications whereases for the wet process still require a lot more test and a separate specification due to the change of the binder behavior used.

In this experiment, the feasibility study of using recycled waste plastic in bituminous concrete in both methods of Wet and Dry process demonstrated as following:

- The optimum plastic content for the dry process is 8% due to the optimum point of the stability test in this process with the acceptable to the MPWT of Cambodia specification.
- The maximum plastic content of the wet process is 8% due to the marshall stability still continue to increase which require more test for the further discussion.
- The stability value showed an increase in the addition of recycled waste plastic compared to conventional bituminous concrete.

The wet process will substantially affect the air voids in the bituminous concrete more than the dry process and also highly effect to the Marshall stability. Base on the current result, the dry process will be recommend to use in the road constrution due to the effective of the workability and provide the acceptable result with the standard specification in Cambodia. It can be concluded that plastic waste has great potential to be used as a modifier in the bitumen for road application The result obtained from the present investigations shows the superiority of recycled plastic waste modified mixes over conventional mixes. Therefore, recycled plastic waste and bitumen combinations may recommend for heavy traffic roads.

References

Al-Hadidy, A. I., & Yi-qiu, T. (2009). Mechanistic approach for polypropylene-modified flexible pavements. Materials and Design, 30(4), 1133–1140. https://doi.org/10.1016/j.matdes.2008.06.021

Beresford, N. (2023). Project Title : Combatting Marine Plastic Litter in Cambodia Implementing Partner : National Council for Sustainable Development Start Date January 2021 End Date : July 2023 L PAC Meeting Date : 10 December 2020 Brief Description The project aims to prove. December 2020.

Bhardwaj, A., Keshav, B. K., & Singh, A. (2017). Review Paper on Application of Waste Plastic in Modifying Bitumen Properties. International Journal of Engineering Research and Applications, 07(04), 79–81. https://doi.org/10.9790/9622-0704047981

Hansen, K., McGennis, R., Prowell, B., & Stonex, A. (2000). Current and Future Use of Non-bituminous components of Bituminous Paving Mixtures. Transportation in the New Millenium, A3B05: Com, 6. ://onlinepubs.trb.org/onlinepubs/millennium/00079.pdf

Keo Rathana. (2009). About Cambodian Institute for Cooperation and Peace (CICP). http://www.cicp.org.kh

Mashaan, N., Chegenizadeh, A., & Nikraz, H. (2021). Laboratory properties of waste PET plastic-modified asphalt mix. Recycling, 6(3), 4–13. https://doi.org/10.3390/recycling6030049

Mashaan, N. S., Chegenizadeh, A., Nikraz, H., & Rezagholilou, A. (2021). Investigating the engineering properties of asphalt binder modified with waste plastic polymer. Ain Shams Engineering Journal, 12(2), 1569–1574. https://doi.org/10.1016/j.asej.2020.08.035

Papacostas, A. (n.d.). Use of Road-grade Recycled Plastics for Sustainable Asphalt Pavements Towards the Selection of Road-grade Plastics – An Evaluation Framework and Preliminary Experimental Results.

Yagasa, R., Uch, R., & Sam, P. (2019). Solid Waste Management in Cambodia. 27, 56–85. https://doi.org/10.4018/978-1-7998-0198-6.ch003